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# DESIGN OF A MEDIUM POWER DC TO 115 VOLT, 60 HERTZ AC INVERTER

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ABSTRACT

The design of a medium power dc to 115 volt, 60 hertz, ac inverter is discussed. A treatment of the conventional design is presented. An alternative design is recommended which offers a considerable size and weight reduction over the conventional design.

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*Author*

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## DESIGN OF A MEDIUM POWER DC TO 115 VOLT, 60 HERTZ AC INVERTER.

The Atmospheric Explorer Satellite, AE-B, is a spherically shaped spacecraft designed to measure the density, composition, pressure and temperature of the earth's atmosphere. This direct-measurement data will help define the structure of the atmosphere on a global basis. The study of the physics of the upper atmosphere will be aided thereby, and our knowledge of solar-terrestrial relationships will be extended. The spacecraft is to be hermetically-sealed to contain any internal contaminants, and prevent them from interfering with the measurements. The primary power source for the spacecraft consists of a bank of silver oxide-zinc batteries. Since this type of battery outgasses hydrogen, during stand, charge and discharge, and oxygen during an overcharge, excessive internal pressures could develop after a period of time. In order to preclude pressure build-up, a plan for venting the spacecraft was proposed. This would be accomplished by periodically opening and closing a valve by ground command. A readily available valve manufactured by the Granville-Phillips Company, Boulder, Colorado was considered for this purpose. The valve, as furnished, is driven by an ac motor requiring an input of 115 volts at a frequency of 60 hertz. In order to use this valve without modification, an ac voltage source would be required. In addition to the voltage level and frequency specified above, this source would also have to be capable of furnishing 11.5 watts to the motor. Keeping the size and weight of the voltage source to an absolute minimum was of prime importance. An attempt was made to determine if such an ac voltage could be developed from the available dc sources.

The simplest approach would be to use a conventional dc to ac square wave inverter operating at a frequency of 60 hertz. Such an inverter using a transformer-coupled multivibrator is shown schematically in Figure 1. Basically the operation of this circuit is as follows: The B-H hysteresis curve for the magnetic core material used in the transformer is indicated in Figure 2. The H-axis represents the magnetizing force applied to the core and is related to the magnetizing current in the transformer. The B-axis indicates the flux generated in the core as a result of the applied magnetizing force. The transformer is operated between regions P and Q of this curve, which are the saturation levels. Between these extremes a maximum amount of flux is generated. Referring to Figure 1 when a dc potential is first applied current starts to flow from the dc voltage source  $E_1$  through transistors  $Q_1$  and  $Q_2$ . Minor differences in the transistors will allow the collector current in one transistor to slightly exceed that of the other transistor. Assuming the current in transistor  $Q_1$  exceeds that in

transistor  $Q_2$ , the current in winding  $N_{P_1}$  induces voltages in windings  $N_{P_2}$  and  $N_{F_2}$  of a polarity to bias transistor  $Q_2$  in the off state. At the same time a voltage is induced in winding  $N_{F_1}$  of a polarity which allows transistor  $Q_1$  to conduct heavily. As a result, regenerative action takes place and transistor  $Q_1$  is driven into saturation. The winding  $N_{P_1}$  assumes the role of a saturable reactor, i.e., as the core tends to saturate (region P on the B-H loop) the inductance of this winding drops to a very low value. Associated with this drop in inductance is an increase in the magnetizing current of the core. But transistor  $Q_1$  is no longer capable of providing the current necessary to keep the core saturated, since the collector current is limited by the base drive resistor  $R_2$ . Hence, the induced voltage falls to zero and transistor  $Q_1$  tends to turn off. This amounts to a flux change reversal which reverses the polarity of the windings and causes transistor  $Q_2$  to turn on. Regenerative action again takes place until the core saturates in the opposite direction (region Q on the B-H loop). From then on the cycle repeats itself at a frequency determined by the core characteristics. The end result is a square wave voltage appearing across the secondary winding of a magnitude proportional to the input voltage, and determined by the ratio of the number of turns of the primary and secondary windings. The resistor  $R_1$  provides a bias which will aid in starting the oscillator when power is first applied.

The basic magnetic equations required for the design of the toroidal transformer  $T_1$  are as follows:

$$V = 4B_m f N A_c \times 10^{-8} \quad (1)$$

where  $V$  = the primary voltage in volts

$B_m$  = the flux density of the magnetic core material in gauss

$f$  = the operating frequency of the transformer in hertz

$N$  = the number of turns in the primary

$A_c$  = the cross-sectional area of the core in square centimeters

and 
$$K = \frac{N A_w}{W_c} \quad (2)$$

where  $K$  = the winding factor defined as the ratio of total cross-sectional wire area to core window area

$A_w$  = the cross-sectional wire area in circular mils

$W_c$  = the core window area in circular mils

The core window and cross-sectional areas are physical dimensions of the core. Hence, an indication of the size of a toroidal core can be obtained from the product of these two dimensions, i.e.,  $W_c A_c$ . Rearranging Equation (2) and multiplying by  $A_c$  yields:

$$W_c A_c = \frac{(N A_c) A_w}{K} \quad (3)$$

But from Equation (1)

$$N A_c = \frac{V \times 10^8}{4 B_m f} \quad (4)$$

Therefore

$$W_c A_c = \frac{10^8}{4 B_m K} \frac{V A_w}{f} \quad (5)$$

The quantities  $B_m$  and  $K$  are essentially fixed and  $A_w$  is directly related to the current carrying capability of the wire. Therefore, Equation (5) states that the size of a transformer is directly proportional to the operating power level and inversely proportional to the operating frequency.

In order to meet the previously stated requirements, the input power to the inverter of Figure 1 would be, assuming an 80% inverter efficiency, 14.25 watts. An input of 5 volts dc would require each half of the primary winding to be capable of carrying a current of 2.85 amperes at a 50% duty cycle. Heavy formvar insulated wire of size A.W.G. #18 having a cross-sectional area ( $A_w$ ) equal to 1808 circular mils will satisfactorily handle this current. Selecting orthonol as the core material with a flux density ( $B_m$ ) of 14,500 gauss and using a winding factor ( $K$ ) of 0.1,  $W_c A_c$  equals  $2.6 \times 10^6$ . The smallest standard core meeting this value would be 2.6 inches in diameter and 0.6 inch high. The transformer itself then is quite large, too large to be useful for this particular program.

A second approach is indicated in the block diagram of Figure 3. The required power is first transformed by a dc-to-ac inverter operating at a high frequency. The square wave output of the inverter is then rectified and filtered to produce a dc voltage. Finally this dc voltage is chopped at a repetition rate of 60 hertz to yield the required output. As has been previously shown, the transformer size is reduced for a given power level by increasing the operating

frequency. The frequency selected for this study was 5 khz. This frequency offers a reasonable compromise between efficiency and size. The eddy current power losses at frequencies much larger than 5 khz would cancel the savings in reduced size and weight of the transformer. At this frequency the  $W_c A_c$  product equals  $0.03 \times 10^6$ . A core meeting this requirement would be 0.96 inch in diameter and 0.2 inch high, which is smaller in volume by a factor of 22 than the core required for the circuit of Figure 1. If the dc voltage from the rectifier-filter network is applied to a single transistor acting as a switch, the output would vary between zero and some peak voltage level as indicated in Figure 4. However, this waveform is more of a pulsating dc than an ac voltage. A true ac voltage implies a polarity reversal, i.e., the voltage level varies between a positive peak value and a negative peak value as indicated in Figure 5. In order to obtain this latter waveform a push-pull type of circuit is necessary, i.e., two transistors alternately switched on and off. Since there is no center tap on the load a bridge connection is used as indicated in Figure 6. The switching signal applied to the base of each transistor consists of two low power 60 hz square waves  $180^\circ$  out of phase with each other. During one half cycle of the 60 hz square wave signal,  $Q_1$  is switched on and  $Q_2$  is switched off. Current flows from  $E_1$  through  $Q_1$  and the load. During the second half cycle,  $Q_1$  is switched off and  $Q_2$  is switched on. Current now flows from  $E_2$  through  $Q_2$  and through the load in the opposite direction. The two dc voltage sources  $E_1$  and  $E_2$  are provided by the use of a tapped secondary on transformer  $T_1$ , a full wave bridge rectifier and two output filter capacitors connected as shown in Figure 7.

The complete schematic is shown in Figure 8. In order to establish the feasibility of this method, the switching signal was generated by an inverter of the type previously described. However, any oscillator circuit could be used to generate the switching signal. A circuit incorporating a frequency stability network should be used if frequency stability is important. A transformer such as  $T_2$ , which couples the switching signal to the bases of transistors  $Q_5$  and  $Q_6$  can be made quite small, because the power level involved is small. The circuit while substantially increasing the number of components over that of Figure 1, offers a considerable reduction in overall size and weight. A breadboard model was constructed using the components listed in Table 1. The device was designed for a 14 watt output to drive a Rotron muffin fan which was used as the load. It satisfactorily delivered this power to the fan at an efficiency of 67%. Since this was only a feasibility study, no attempt was made to optimize the circuit elements. If this were done an efficiency of at least 75% could be realized. Three views of the breadboard are shown in Figures 9, 10, and 11. Proper packaging techniques would reduce the size of the unit by at least a factor of 3. In conclusion then this study verifies the practicality of a medium power dc to 115 volt, 60 hertz ac inverter of small size and weight.



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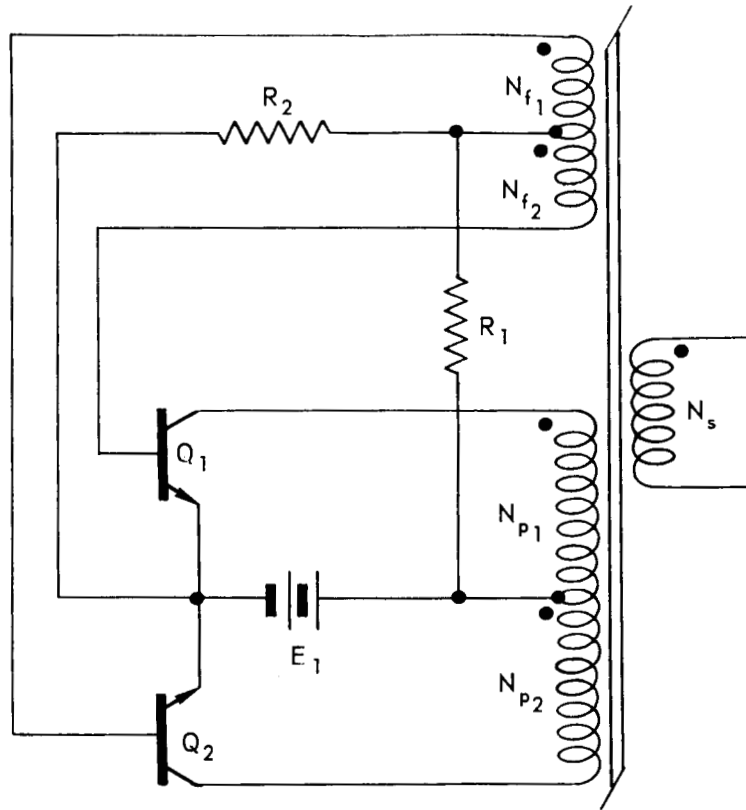


Figure 1—Schematic Diagram, Conventional dc-to-ac Inverter

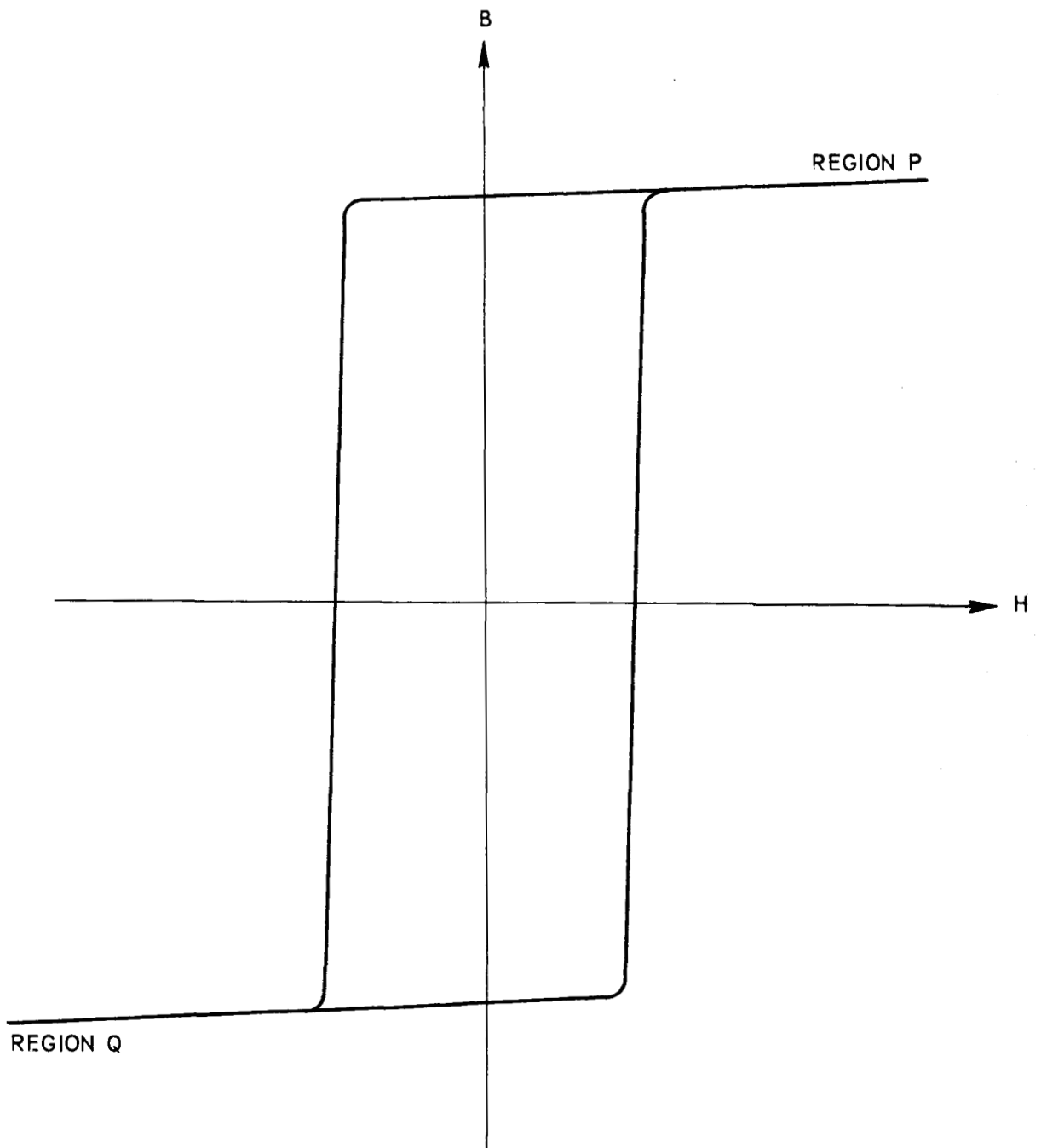


Figure 2-B-H Hysteresis Curve for Magnetic Core Material

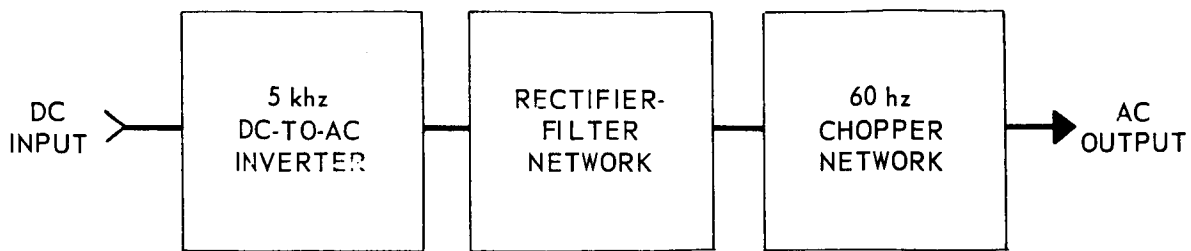


Figure 3—Block Diagram, dc-to-ac Inverter

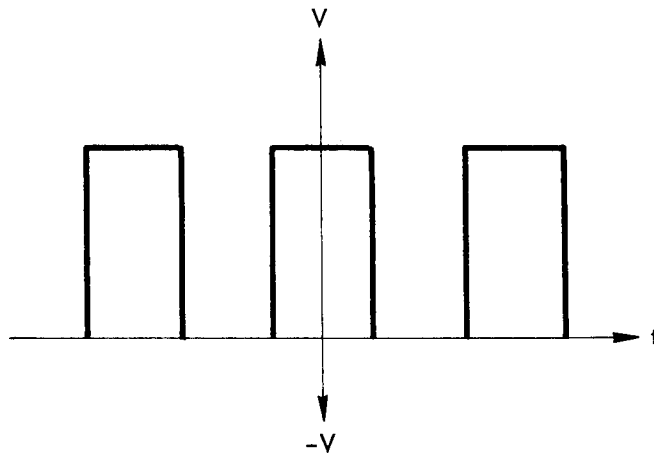


Figure 4—Pulsating dc Voltage Waveform

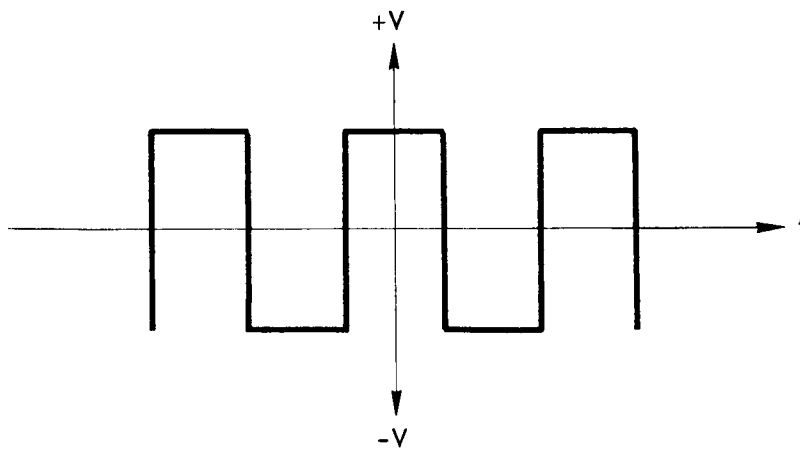


Figure 5—ac Voltage Waveform

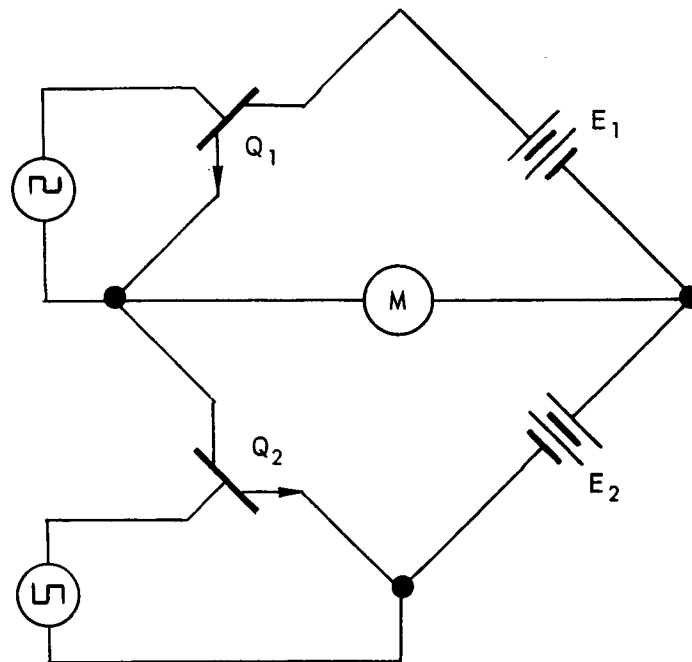


Figure 6-60 hz Chopper Network

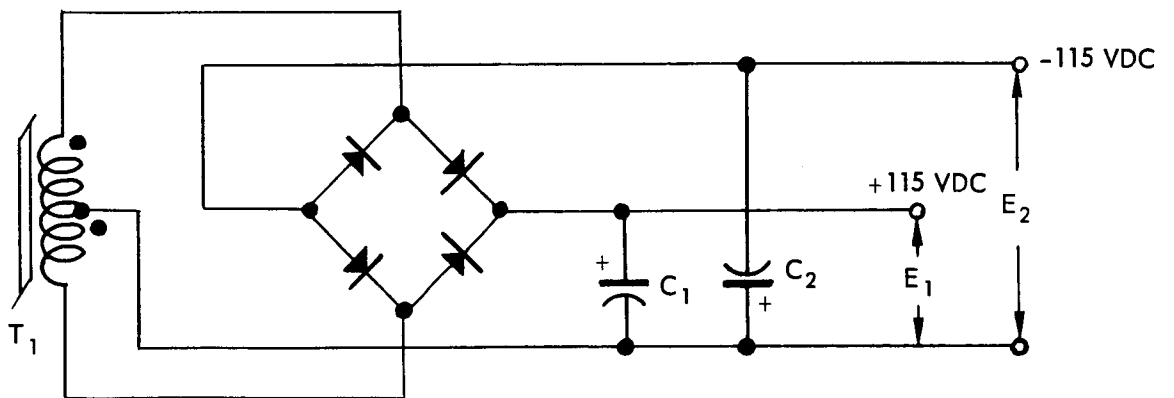


Figure 7-Rectifier Filter Network

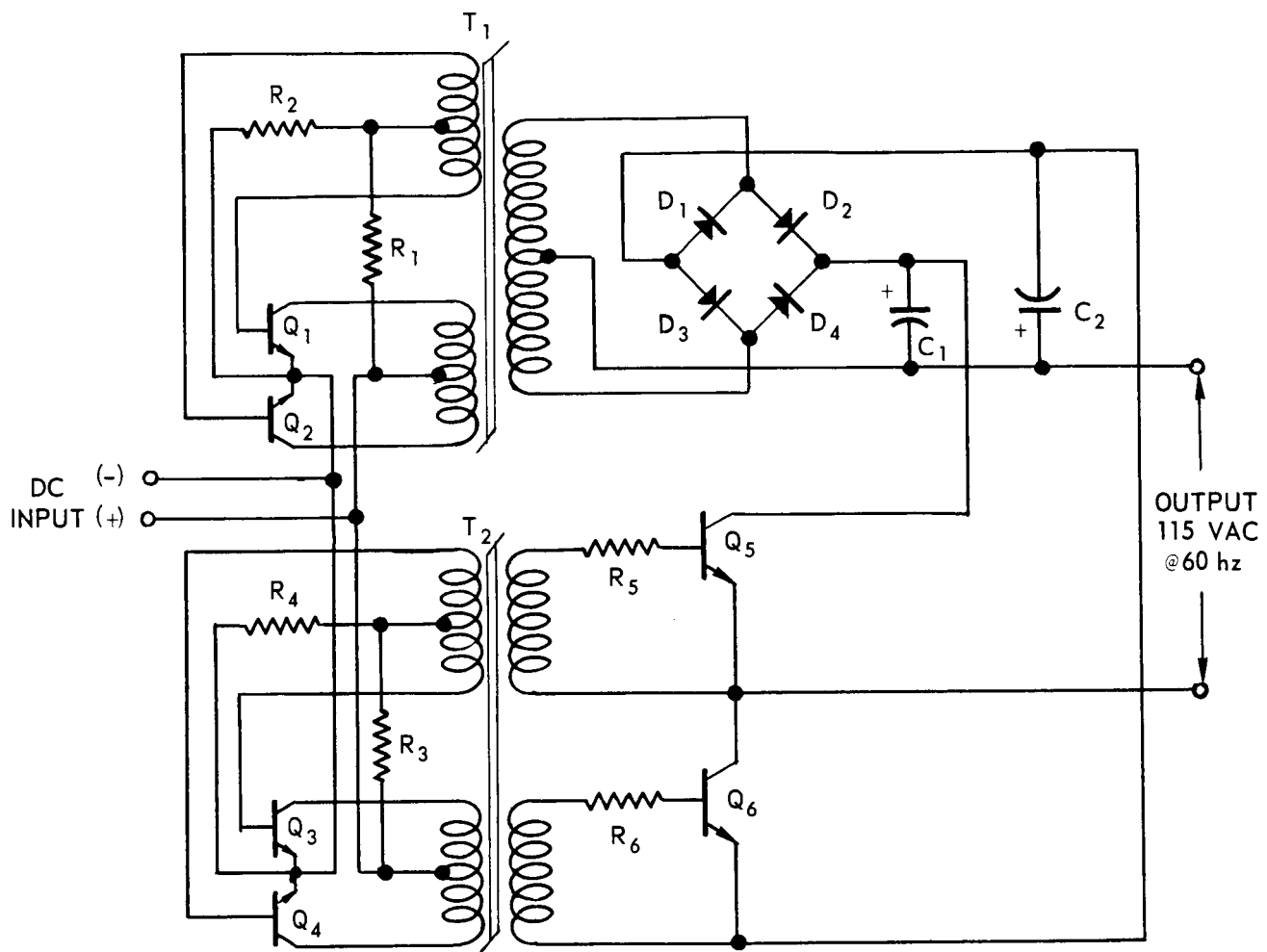


Figure 8—Schematic Diagram, 14 watt, 5 volt dc to 115 volt, 60 hz ac Inverter



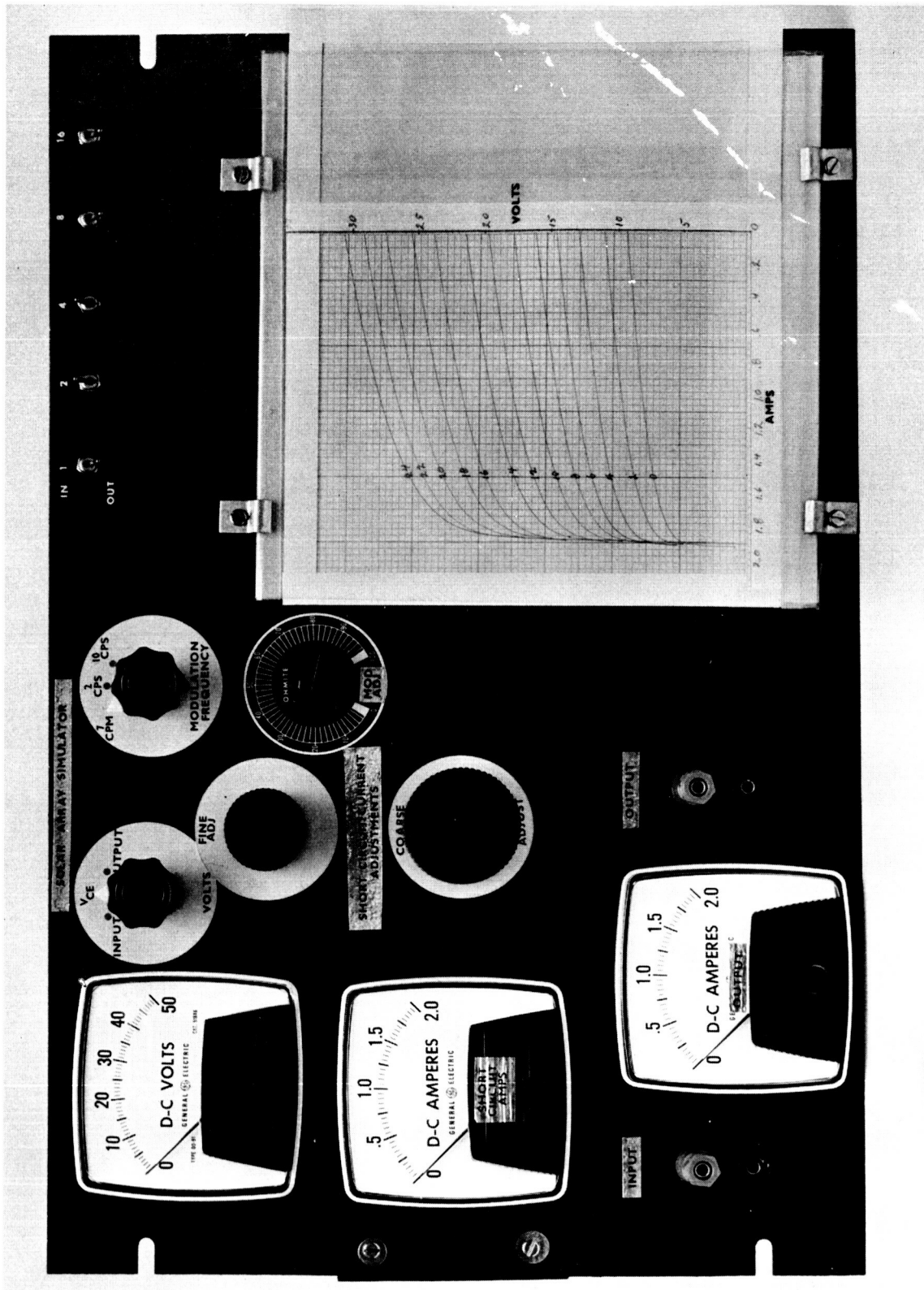


Figure 7 - Solar Array Simulator



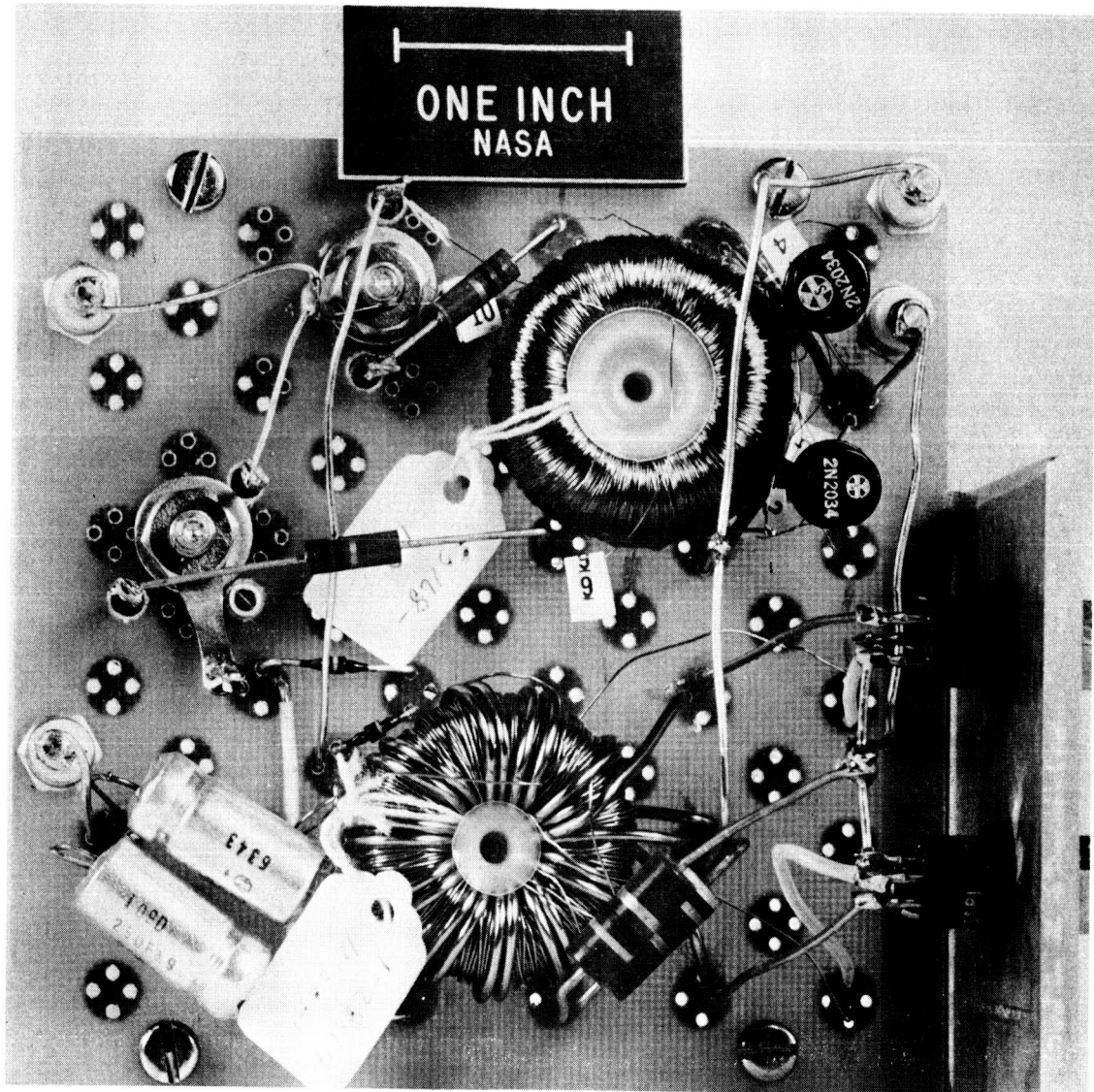


Figure 10—Top View of Breadboard



Figure 11—Bottom View of Breadboard